Institutional report - Cardiac general

Impact of pacing modality and biventricular pacing on cardiac output and coronary conduit flow in the post-cardiotomy patient

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Abstract

We have previously demonstrated the role of univentricular pacing modalities in influencing coronary conduit flow in the immediate postoperative period in the cardiac surgery patient. We wanted to determine the mechanism of this improved coronary conduit and, in addition, to explore the possible benefits with biventricular pacing. Sixteen patients undergoing first time elective coronary artery bypass grafting who required pacing following surgery were recruited. Comparison of cardiac output and coronary conduit flow was performed between VVI and DDD pacing with a single right ventricular lead and biventricular pacing lead placement. Cardiac output was measured using arterial pulse waveform analysis while conduit flow was measured using ultrasonic transit time methodology. Cardiac output was greatest with DDD pacing using right ventricular lead placement only (DDD-univentricular 5.42 l (0.7), DDD-biventricular 5.33 l (0.8), VVI-univentricular 4.71 l (0.8), VVI-biventricular 4.68 l (0.6)). DDD-univentricular pacing was significantly better than VVI-univentricular (P = 0.023) and VVI-biventricular pacing (P = 0.001) but there was no significant advantage to DDD-biventricular pacing (P = 0.45). In relation to coronary conduit flow, DDD pacing again had the highest flow (DDD-univentricular 55 ml/min (24), DDD-biventricular 52 ml/min (25), VVI-univentricular 47 ml/min (23), VVI-biventricular 50 ml/min (26)). DDD-univentricular pacing was significantly better than VVI-univentricular (P = 0.006) pacing but not significantly different to VVI-biventricular pacing (P = 0.109) or DDD-biventricular pacing (P = 0.171). Pacing with a DDD modality offers the optimal coronary conduit flow by maximising cardiac output. Biventricular lead placement offered no significant benefit to coronary conduit flow or cardiac output.

Keywords: Pacing; Biventricular; Cardiac output; Coronary conduit flow; DDD; VVI

1. Introduction

Coronary conduit flow may be an important factor in the success of surgical coronary revascularisation therapy [1]. We have previously demonstrated in the acute surgical scenario an improved coronary conduit flow with DDD pacing compared to VVI pacing with a single ventricular approach [2]. In some patients with heart failure, long-term univentricular pacing has been shown to be inferior to biventricular pacing, which has become an established utility in the management of heart failure patients. This has arisen from the observation of superior survival with long-term AAI pacing in comparison with VVI or DDD pacing [3]. Among patients with long-term DDD pacing, survival is inversely associated with the use of the ventricular component of the device. Long-term biventricular pacing in heart failure has demonstrated superior survival statistics and clinical improvement especially in patients with widened QRS complexes, but benefits have been claimed in patients with normal QRS duration [3, 4]. Ischaemic heart disease with poor ventricular function remains an indication for surgical revascularisation [5].

Although we have previously demonstrated improved coronary conduit flow with DDD pacing compared to VVI pacing with a single ventricular approach, we have not demonstrated the mechanism of action of this improvement [2]. We hypothesised that changes in cardiac output occur and that these result in alterations in coronary conduit flow. Biventricular pacing has also been associated with improved cardiac output [6]. Interestingly, biventricular pacing in heart failure has been reported to improve coronary artery blood flow [7]. We wanted to determine whether there would be an advantage to biventricular pacing in the postoperative cardiac surgery patient in relation to cardiac output and coronary conduit flow.

2. Methods

2.1. Patients

This prospective study was approved by the institutional Ethics Committee with waived informed consent. Patients undergoing first time elective isolated coronary revascularisation were recruited over a six-month period (n = 16) (Table 1). Candidates were recruited if there was evidence of sinus bradycardia (< 60) or heart block requiring pacing.
Aortic cross-clamp Survival 100% CABG
diaphragm, 4
the left ventricle, 3
ventricle, 2

This shows the demographic profile and procedures performed on patients participating in the study

<table>
<thead>
<tr>
<th>Patient number</th>
<th>Male</th>
<th>Age (years)</th>
<th>EuroSCORE</th>
<th>Ejection fraction</th>
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<tbody>
<tr>
<td>16</td>
<td>13 (81%)</td>
<td>67 (±11)</td>
<td>3.13 (±2)</td>
<td>&lt;50% 9</td>
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<td>30–50% 7</td>
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<td>CABG</td>
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<td></td>
<td></td>
<td>Survival 100%</td>
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<td></td>
<td></td>
<td>Aortic cross-clamp (min) 49 (±8.9)</td>
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<td>Cardiopulmonary bypass time (min) 86 (±17)</td>
</tr>
</tbody>
</table>

Exclusion criteria included inotropic support or an intra-aortic balloon pump.

2.2. Pacing performance

Epicardial pacing leads were positioned as follows: 1) negative lead to the anterior surface of the right ventricle, 2) negative lead to the anterolateral aspect of the left ventricle, 3) positive ventricular lead to the diaphragm, 4) negative lead to the right atrium, and 5) positive atrial lead to the diaphragm. The external pulse generator was a Biotronics Era 300 pacing system analyser (Biotronics GmbH, Woermannkehre 1, 12359, Berlin, Germany). Once the patient was successfully weaned off cardiodiaphragmatic bypass support and decannulated, testing was performed prior to closure of the sternum. The following modes were assessed: 1) right ventricular pacing alone, 2) biventricular pacing, 3) atrio-ventricular pacing with right ventricular lead alone, and 4) atrio-ventricular pacing with right and left ventricular leads. For biventricular pacing the contact points of the ventricular leads were placed in the same port of the pacing box. The A.V. delay was set at 135 ms and the rate at 90 bpm. In the order in which the pacing modalities were tested was 1) no pacing, 2) VVI with right ventricular lead, 3) DDD with right ventricular lead, 4) DDD with biventricular leads, and 5) VVI with biventricular leads. The left ventricular lead was removed at the conclusion of the study measurement prior to sternal closure.

2.3. Outcome measurements

Measurements were performed one minute after altering pacing modality. Cardiac electric activity was monitored using a standard continuous electrocardiography monitor. Haemodynamic measurements were determined using an arterial line for blood pressure measurement. Coronary conduit flow was measured using the transit time flow measurement (TTFM) device. Flow probes were placed around the grafts. Aqueous contact gel is placed between the probe and conduit. The probe consists of two small piezo-electric crystals mounted on the same side of the vessel. Opposite to the crystals is a metallic reflector. Each crystal produces a wide pulsed ultrasound beam covering the width of the vessel. The amount of time necessary for the ultrasound signal to pass between the crystals is measured. The time difference between the two signals is used to calculate flow. All calculations are automated by the flow meter and measured in ml/min. Only saphenous vein grafts with a single distal anastomosis were used for measurement. The target vessel differed among patients but all patient measurements were performed within the same graft which served as an internal control. Cardiac output was measured using the Vigileo non-invasive method. This device does not require pulmonary artery catheterisation but rather calculates cardiac output using the arterial waveform. A dedicated transducer is connected to the arterial line for arterial pulse wave cardiac index measurement (Vigileo System, FloTrac Edward’s Lifesciences, Irvine, CA, USA). The system consists of a sensor (FloTrac) and a processing display unit (Vigileo). The processor generates a cardiac output, cardiac index, stroke volume and stroke volume index as well as the systemic vascular resistance. The device reports variables at 20 s intervals using the most recent 20 s of data.

2.4. Statistics

Each patient served as their own internal control. Comparison between paired data was tested with a paired t-test with a Bonferroni correction for multiple comparisons. Alpha was set at 0.025.

3. Results

3.1. Patient profile

Sixteen patients were recruited. All patients underwent first time isolated coronary artery bypass grafting. The mean number of bypass grafts was 3.1. The majority of patients were male. The mean age was 67 years and the mean EuroSCORE was 3.13. No patient had an ejection fraction <30% (Table 1). All patients survived to discharge.

3.2. Coronary conduit flow

Ventricular pacing with a right ventricular lead had the lowest rate of coronary conduit flow for a pacing modality. Addition of atrial pacing significantly improved coronary conduit flow with average flow rates increasing from 47 ml/min with VVI, up to 55 ml/min with DDD pacing (P = 0.006). This confirmed our previously published observations [2]. However, addition of a biventricular mode offered no significant benefit over a single ventricular approach with ventricular pacing (P = 0.129) or with atrio-ventricular pacing (P = 0.171) (Table 2). The optimum pacing regime therefore was a DDD pacing mode with a right atrial and right ventricular lead placement. Analysis of patients with good and moderate ejection fractions showed no difference in response to biventricular pacing.

3.3. Cardiac output

Ventricular pacing with a right ventricular lead generated the lowest cardiac output among the paced modalities. The addition of atrial pacing significantly improved cardiac
output from 4.7 l/min up to 5.4 l/min (P = 0.023). The addition of a biventricular mode did not significantly improve cardiac output when compared with a single right ventricular approach (P = 0.89) or atrio-ventricular pacing (P = 0.45) (Table 2). The optimal cardiac output was achieved with DDD pacing with right ventricular lead placement. Analysis of patients with good and moderate ejection fractions showed no difference in response to biventricular pacing. Blood pressure was significantly better with atrio-ventricular pacing compared to ventricular alone (VVI-right ventricular lead 94/49 mmHg, DDD-right ventricular lead 103/55 mmHg, P < 0.01). However, there was no significant difference in blood pressure when a right ventricular lead was used alone or when biventricular pacing was performed.

4. Discussion

Coronary conduit flow is an important component in long-term patency of coronary artery bypass grafts [1, 8]. The failure rate among vein grafts is particularly high in the early postoperative period and it is estimated that 5–7% have occluded within one month of surgery [9]. We have previously demonstrated that the immediate postoperative pacing modality impacts on coronary conduit flow, but we had not demonstrated the mechanism by which this is achieved [2]. The flow rate can be influenced by the quality of the anastomosis, lumen of the conduit, arterial pressure and cardiac output, downstream vessel runoff and duration of diastole. We have again demonstrated that DDD pacing significantly improves coronary conduit flow. In addition, we have now demonstrated that this is the result of improved cardiac output generated by DDD pacing. Atrio-ventricular pacing offers benefits of synchronisation of atrial and ventricular units. There is little additional myocardial energy demand and complications following epicardial pacemaker wire removal have been reported but are rare. The placement of atrio-ventricular leads therefore appears to be the optimal pacing strategy in the post-cardiac surgery patient.

Biventricular pacing was initially attractive as a potential strategy to further improve coronary conduit flow and cardiac output. The cost of an additional lead is minimal, with minimal additional morbidity to the patient and no additional myocardial energy demand. Biventricular pacing in poor left ventricles with bundle branch block is associated with improved cardiac output and coronary flow [7]. Isolated right ventricular pacing lead placement requires myocardial conduction of depolarization through the right ventricle to the left and is slower than the His-Perkinje system. This results in dys-synchrony between the two ventricles. Over time this leads to histological changes in the myocardium and is associated with accelerated deterioration of heart failure. Biventricular pacing also narrows the QRS complex duration in patients with heart block which may have consequent beneficial effects on coronary conduit flow by altering the duration of diastole. However, in our studies we observed no significant benefits to cardiac output or coronary conduit flow among our population with biventricular pacing.

An explanation for our findings may be that our population had normal or moderate ventricles. A small (n = 7) study suggested 10% improvement in cardiac output, with patients with moderate ventricular function and heart block, although this group did not investigate coronary conduit flow [10]. A larger study in a postoperative cardiac surgery population of patients with ejection fractions less than 35% demonstrated mixed results [11]. No improvement was seen in 41% (22/54) of patients, but in 59% (32/54), cardiac output improved with biventricular pacing. However, this study did not control for inotropic support and 46% (15/32) of patients with an improved cardiac output with biventricular pacing were also on inotropic support. In attempting to minimise variability, we excluded patients requiring inotropic support, but this largely excluded patients with very poor ventricles. This may have resulted in exclusion of patients who may benefit the most from biventricular pacing. The majority of patients in this study had normal ventricular function. However, subgroup analysis of patients with moderately impaired ventricles identified no significant benefits with biventricular pacing within this group. Others have also reported no immediate benefit with biventricular pacing in the postoperative period among post-cardiac surgery patients with poor left ventricle function in terms of function [12]. A report of biventricular pacing in a post-cardiomyopathy patient with right ventricular failure also demonstrated no additional benefit of biventricular pacing over standard DDD pacing [13].

In this paper we chose to place a single left-sided lead at a single site. There is much controversy regarding the optimal site for lead placement. Alternative sites of left ventricular lead placement may yet demonstrate some benefits. Published work in heart failure patients suggests that the lateral and anterolateral aspect of the left ventricle are the optimal sites but this work has not been performed in the post-cardiomyopathy patient. However, there appears to be great individual variability in the optimum site for left ventricular pacing [14]. One interesting approach is to use the QRS duration to identify the optimum position. Alternatively, more subtle pacing delays between the left and right leads might offer benefits. In our experimental design we activated the right and left ventricular leads simultaneously. However, alternative approaches with...
varying the timing have proven to be of some benefit in heart failure management [15]. The significant benefits of DDD over VVI would suggest that atrio-ventricular pacing regimes must be preferred. In patients with normal and moderate left ventricle function we conclude that there is no additional benefit to biventricular pacing. Further exploration and optimisation may be warranted in patients with poor ventricles before any additional utility for biventricular pacing is demonstrated. We conclude that DDD pacing with right ventricular lead placement offers the optimum conduit flow and cardiac output.

References

[14] Dekker A, Phelps B, Dijkman B, van Der Nagel T, van Der Veen F, Geskes E, Bogaert P, Morschke K. Early and sustained effects of cardiac resynchronization therapy on cardiac output and coronary conduit flow in the post-cardiomyopathy patient [1]. DDD pacing was associated with the best cardiac output determined by arterial pulse waveform analysis with the Vigileo system (FlOTrac Edward’s Lifescience, Irvine, CA, USA). The authors found that in their patient cohort biventricular pacing was not associated with improved cardiac output or improved coronary conduit flow. Only a limited number of patients with only minor impairment of cardiac pump function were involved in the study, which might at least in part explain the aforementioned results. A recent study supports this finding [2]. Twenty-one consecutive patients with an ejection fraction < 35% underwent hemodynamic evaluation (continuous pressures and thrombolization) 3, 6, and 18 h post-CABG and biaxial (AA), biaxial-right ventricular (AAR), and biaxial: biventricular (AAM) pacing were compared. Cardiac output (CO) was determined as an average of three measurements by thrombolization over 6 min using 10 ml ice-cold water for injection. The authors found that biventricular pacing improves CI in patients with poor EF following cardiac surgery in the absence of preoperative atrioventricular- or interventricular conduction block. This benefit decreases with time after surgery as the QRS width returns to preoperative values. Four-chamber pacing did not confer additional benefit as compared to biventricular pacing in this series. Biventricular pacing should be considered as an adjunct in patients with critically low EF undergoing cardiac surgery. In addition, both the mode of cardiac output determination as well as the mode of coronary conduit flow might have influenced their findings, which is not addressed in detail in the paper. Ultrasonic cardiac output monitoring (USCOM, Sydney, Australia) has been reported to be a simple, accurate and fast non-invasive method for the optimization of atrio-ventricular interval (AVI) in cardiac resynchronization therapy (CRT) [3]. Currently, no such study exists to the best of my knowledge for the aforementioned Vigileo invasive system. Last, it would be interesting how cardiac markers such as nt-pro-BNP might be influenced by the mode of pacing in future studies. A close relationship between non-invasive cardiac output determined by ultrasonic cardiac output monitoring (USCOM) and nt-pro-BNP levels in cardiotoxicity monitoring has been reported [4]. The Cardiac Resynchronization-Heart Failure (CARE-HF) study demonstrated that cardiac resynchronization therapy (CRT) could reduce morbidity and mortality and improve cardiac function in patients with moderate or severe heart failure secondary to left ventricular systolic dysfunction. Nt-pro-BNP reduction has been observed following CRT in responders [5]. Thus, nt-pro-BNP monitoring might be a simple and appropriate method to study the effects of different pacing modes such as CRT or postoperative biventricular or quadruple pacing in cardiac surgery patients.

References